



Original Article

The effects of gluteus maximus and abductor hallucis strengthening exercises for four weeks on navicular drop and lower extremity muscle activity during gait with flatfoot

YOUNG-MI GOO, MS, PT¹⁾, TAE-HO KIM, PhD, PT^{1)*}, JIN-YONG LIM, MS, PT¹⁾

¹⁾ Department of Physical Therapy, College of Rehabilitation Science, Daegu University: 15 Jillyang, Gyeongsan-si, Gyeongsangbuk-do 712-714, Republic of Korea

Abstract. [Purpose] The purpose of the present study is to examine the effects of abductor hallucis and gluteus maximus strengthening exercises on pronated feet. [Subjects and Methods] The present study was conducted with 18 adults without no history of surgery on the foot or ankle. One group performed both gluteus maximus strengthening exercises and abductor hallucis strengthening exercises, while the other group performed only abductor hallucis strengthening exercises five times per week for four weeks. [Results] The group that performed both gluteus maximus and abductor hallucis strengthening exercises showed smaller values in the height of navicular drop than the group that performed only abductor hallucis strengthening exercises. The muscle activity of the gluteus maximus and the vastus medialis increased during heel-strike in the group that added gluteus maximus exercises, and the muscle activity of the abductor hallucis significantly increased in both groups. [Conclusion] Given the results of the present study, it can be suggested that strengthening the gluteus maximus while also performing exercises to correct the pronated foot is an effective method for achieving normal gait.

Key words: Navicular drop, Foot arch, Walking

(This article was submitted Oct. 23, 2015, and was accepted Dec. 12, 2015)

INTRODUCTION

The feet support the body's weight and play the role of levers when an individual is performing work¹⁾. The body weight normally falls on the center of the foot, and balance is maintained by the muscle activity of the foot²⁾. If the foot becomes diseased or deformed, the foot adapts to perform its functions under the conditions of disease or deformity³⁾. Weakening of the gluteus maximus is a cause of foot deformities that induces the hip joint to internally rotate and the foot to pronate⁴⁾.

Within the sole are the lateral longitudinal arch, the medial longitudinal arch (MLA), and the transverse arch⁵⁾. The MLA is controlled with the assistance of bone structures, ligaments, and the extrinsic and intrinsic muscles of the foot⁶⁾. Among these muscles, the abductor hallucis (AbdH) has been reported to control excessive foot pronation⁷⁾. The AbdH has also been reported to be important for stabilization of the MLA and indispensable for toe-off during gait⁸⁾. Although there are many exercises for strengthening the AbdH, the toe-spread (TS) exercise has been shown to achieve higher levels of AbdH muscle activity in when compared to the short-foot exercise; however, the difference was not statistically significant when both exercises were performed in the sitting position⁹⁾.

Among selective gluteus maximus strengthening exercises, the one performed by slightly lifting the knee while maintaining the hip joint in external rotation and the knee joint at 90° flexion while in the prone position was reported to be the most effective¹⁰⁾.

*Corresponding author. Tae Ho Kim (E-mail: ptkimth@daegu.ac.kr)

©2016 The Society of Physical Therapy Science. Published by IPEC Inc.

This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License <<http://creativecommons.org/licenses/by-nc-nd/4.0/>>.

Although there is literature indicating that the plantar arches and the iliacus muscle affect each other, studies identifying the effect are rare. Therefore, subjects were divided into two exercise groups in this study: one group strengthened only the abductor hallucis (which directly affects the plantar arches), while the other group strengthened both the abductor hallucis and the gluteus maximus. The lower-extremity muscle activity levels of the two groups during the gait were compared in order to propose the most effective method to strengthen the MLA.

SUBJECTS AND METHODS

A total of 18 healthy adults were selected after excluding subjects with a history of arthritis, foot or ankle surgery, diabetes, foot abnormalities, or present cuts to the lower extremities. The study subjects were selected from among those who had foot pronation (>10 mm) based on navicular drop (ND) tests¹¹. The participants were provided with a written informed consent form in accordance with the ethical standards of the Declaration of Helsinki. The mean age, height, and weight of the study subjects who strengthened both the gluteus maximus and the AbdH simultaneously were 21.89 ± 1.69 years, 163 ± 7.26 cm, and 57.56 ± 14.33 kg, respectively. The mean age, height, and weight of the study subjects who strengthened only the AbdH were 22.3 ± 2.06 years, 164.7 ± 8.53 cm, and 62.22 ± 12.04 kg, respectively.

The study subjects performed their respective exercises three times per week in the laboratory and two times per week at home for four weeks. The subjects who performed both gluteus maximus and TS exercises did three sets of 20 repetitions of exercises that selectively strengthened the gluteus maximus in the prone position and 100 repetitions of TS exercises in the sitting position while maintaining both the hip joints and the knee joints at 90° flexion. The subjects in the other group performed only 100 repetitions of TS exercises.

A surface electromyographic (EMG) DTS system (TeleMyo DTS, Noraxon Inc., AZ, USA) was used to record and process the EMG signals from the gluteus maximus, the vastus medialis, the tibialis anterior, and the AbdH. For the gluteus maximus, the EMG electrodes were placed at the midpoint of the sacral vertebrae and the greater trochanter. EMG electrodes for the vastus medialis were placed four-fifths of the way along a line from the ASIS and the joint space in front of the anterior border of the medial ligament, while electrodes for the tibialis anterior were placed $1/3$ on the line between the tip of the fibula and the tip of the medial malleolus. Electrodes for the abductor hallucis were placed approximately 1–2 cm posterior to the navicular tuberosity. Single electrodes were used for the surface EMG. The signals were extracted at a rate of 1,500 Hz and noises in raw EMG signals were removed through 20–500 Hz bandpass filters and 60 Hz notch filters. The muscles' EMG signals were processed into root mean square (RMS), and the EMG data were analyzed using the MyoResearch Master 1.07 XP program (Noraxon Inc., AZ, USA). After determining the three most stable gait cycles, we found average values of heel-strike, foot-flat, toe-off muscle activity. The EMG data were normalized to maximal voluntary contraction (% MVC).

Statistical analyses were conducted using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA). ND's¹² before and after group exercises were compared using independent t-tests. Paired t-tests were used to measure changes in lower extremity pre- and post-exercise EMG measurements in each group. Foot switches were attached to the center of the heel, below the first and fifth metatarsals, before walking in order to divide the gait cycle into the heel-strike, foot-flat, and toe-off phases; lower extremity EMG was performed in each individual phase. The significance level was set to $p < 0.05$.

RESULTS

The ND was 5.53 ± 1.58 in the group that performed both gluteus maximus and TS exercises and 7.63 ± 2.27 in the group that performed only TS exercises. Therefore, the ND in the group that performed both gluteus maximus and TS exercises decreased significantly more than the group that performed only TS exercises (Table 1). The % MVC values of the gluteus maximus ($11.97 \pm 7.26\%$) and the vastus medialis ($13.25 \pm 8.38\%$) were significantly increased during heel-strike, and the % MVC value of the AbdH ($13.1 \pm 13.47\%$) was significantly increased during toe-off in the group that performed both gluteus maximus and TS exercises (Table 2). In the group that performed only TS exercises, the % MVC value for the AbdH ($11.58 \pm 13.46\%$) was significantly increased during toe-off (Table 2). After four weeks, there was no significant difference between combined gluteus maximus and TS exercise and only TS exercise (Table 3).

DISCUSSION

In a study that used insoles for MLA correction, the researchers stated that this was not recommendable because inconvenience in the lower extremity related to physical stress was not improved¹³. O'Sullivan reported that when subjects with pronation received MLA support with tape and had their standing foot pressure measured the results indicated that pressure was decreased in the front and middle parts of the feet¹⁴. Similarly, in a study conducted by Franettovich et al., taping was applied to five subjects with pronated feet and the researchers identified that the height of the MLA increased and excessive muscle use decreased compared to levels measured without taping¹⁵; however, in relation to muscle activity, the researchers advised that they could not know how taping increased the height of the arch of the foot. Given these results, short-term effects can be expected from using aids for maintaining or increasing the height of the MLA, but long-term effects cannot be expected; also, no effect can be expected when no aid is used. Many studies have been conducted on various exercise

Table 1. Comparison of ND test results between the group that performed both gluteus maximus (GM) and TS exercises and the group that performed only TS exercises (n=18)

		GM exercises and TS exercises Mean (SD)	TS exercises only Mean (SD)
Pre	ND (mm)	11.9 (2)	11.4 (1.4)
4 weeks	ND (mm)	5.5 (1.6)	7.6 (2.3)*

GM: gluteus maximus, TS: toe spread, ND: navicular drop, SD: standard deviation
*p<0.05

Table 2. %MVC values before and after exercises (n=9)

		GM exercises and TS exercises		TS exercises only	
Muscle		Pre Mean (SD)	4 weeks Mean (SD)	Pre Mean (SD)	4 weeks Mean (SD)
Heel strike	GM	21.5 (11.8)	33.4 (11.5)*	17.7 (12.7)	22.1 (14.4)
	VMO	27.1 (11.2)	40.3 (9.7)*	21.3 (16.2)	26.2 (7.4)
	TA	29.4 (10.8)	29.4 (9.8)	21.9 (12.4)	28.4 (8.8)
	AbdH	16.2 (6.8)	17 (9.5)	18.3 (8.8)	20.5 (6)
Foot flat	GM	17.7 (13.3)	18.2 (10.7)	10.8 (6.4)	12.8 (4.9)
	VMO	26.8 (18.5)	22.2 (7.8)	13 (4.6)	15.9 (4.2)
	TA	15.1 (8.9)	17.5 (9.5)	16.1 (13.1)	16.8 (10.6)
	AbdH	15.9 (9.5)	22.3 (9.9)	18.6 (10.2)	22.3 (7)
Toe off	GM	11.5 (13.3)	14 (10.2)	10 (8.7)	16.3 (12.1)
	VMO	12 (8.4)	14.4 (5.5)	12.9 (13.2)	17.9 (14.2)
	TA	16.9 (7.7)	15.2 (3.4)	15.8 (16.1)	11 (5)
	AbdH	28.5 (11.1)	41.6 (10.3)*	28 (14.4)	39.6 (11.4)*

GM: gluteus maximus, VMO: vastus medialis, AbdH: abductor hallucis, TS: toe spread, SD: standard deviation, MVC: maximal voluntary contraction
*p<0.05

Table 3. Comparison of %MVC values between the group that performed both gluteus maximus and TS exercises and the group that performed only TS exercises after 4 weeks (n=18)

Muscle		GM exercises and TS exercises Mean (SD)	TS exercises only Mean (SD)
Heel strike	GM	33.4 (11.5)	22.1 (14.4)
	VMO	40.3 (9.7)	26.2 (7.4)
	TA	29.4 (9.8)	28.4 (8.8)
	AbdH	17 (9.5)	20.5 (6)
Foot flat	GM	18.2 (10.7)	12.8 (4.9)
	VMO	22.2 (7.8)	15.9 (4.2)
	TA	17.5 (9.5)	16.8 (10.6)
	AbdH	22.3 (9.9)	22.3 (7)
Toe off	GM	14 (10.2)	16.3 (12.1)
	VMO	14.4 (5.5)	17.9 (14.2)
	TA	15.2 (3.4)	11 (5)
	AbdH	41.6 (10.3)	39.6 (11.4)

GM: gluteus maximus, VMO: vastus medialis, AbdH: abductor hallucis, TS: toe spread, SD: standard deviation, MVC: maximal voluntary contraction

methods using muscles directly connected to the MLA to supplement such shortcomings. Since many studies set the criterion for pronated feet as 10 mm or greater ND¹⁶⁾, the subjects in the present study were selected based on that criterion. Subjects were randomly divided with one group of nine subjects performing both gluteus maximus and TS exercises three times per week for four weeks, while another group of nine subjects performed only TS exercises. Feet with smaller values in the height of the ND were less pronated, and the group that added gluteus maximus strengthening exercises showed decreased values in the height of the ND compared to the group that performed only TS exercises. The gluteus maximus is an external rotation muscle of the hip joint, and it is proposed to have externally rotated the alignment of the lower extremity to reduce the foot pronation in these patients.

In normal gait, it is said that the muscle activity of the gluteus muscle group, the quadriceps, and the tibialis anterior increases during heel-strike and that the muscle activity of the calf muscle and the intrinsic foot muscles increases during toe-off⁵⁾. The group that performed both gluteus maximus and TS exercises showed significantly higher muscle activity of the gluteus maximus and the vastus medialis during heel-strike and high muscle activity of the AbdH during toe-off, while the group that performed only TS exercises showed only increased muscle activity of the AbdH during toe-off. When compared to the muscle activity during normal gaits reported by Neumann⁵⁾, the group that added gluteus maximus strengthening exercises showed muscle activity much closer to that of normal gaits. Given the changes in the height of the ND and the changes in the EMG of the lower extremity during gait, strengthening both the TS and the gluteus maximus is considered more effective for correction of the MLA than performing only TS exercises.

The present study has some limitations. First, in determining the criteria for subjects' normal feet, ND tests were not sufficient, and the number of subjects was not large enough for generalization. In addition, although the AbdH is the most superficial muscle of the foot, it is a small muscle and is susceptible to cross talk from other intrinsic and extrinsic muscles. Another limitation is the fact that changes over time were not assessed after the four-week exercise intervention period was over. Future studies should consider these limitations and conduct motion analyses and radioactive examinations to study diverse methods of MLA correction.

ACKNOWLEDGEMENT

This research was supported by the Daegu University Research Grant, 2013.

REFERENCES

- 1) Lephart SM, Pincivero DM, Rozzi SL: Proprioception of the ankle and knee. *Sports Med*, 1998, 25: 149–155. [[Medline](#)] [[CrossRef](#)]
- 2) Lees A, Lake M, Klenerman L: Shock absorption during forefoot running and its relationship to medial longitudinal arch height. *Foot Ankle Int*, 2005, 26: 1081–1088. [[Medline](#)]
- 3) Whitman R: A study of the weak foot, with reference to its causes, its diagnosis, and its cure: with an analysis of a thousand cases of so-called flat-foot. *J Bone Joint Surg Am*, 1896, 1: 42–77.
- 4) Kendall FP, McCreary EK, Provance PG, et al.: *Muscles: Testing and function with posture and pain*, 5th ed. Philadelphia: Lippincott Williams & Wilkins, 2005.
- 5) Neumann DA: *Kinesiology of the musculoskeletal system: Foundations for rehabilitation*, 2nd ed. Missouri: Mosby, 2010.
- 6) Franco AH: Pes cavus and pes planus. Analyses and treatment. *Phys Ther*, 1987, 67: 688–694. [[Medline](#)]
- 7) Fiolkowski P, Brunt D, Bishop M, et al.: Intrinsic pedal musculature support of the medial longitudinal arch: an electromyography study. *J Foot Ankle Surg*, 2003, 42: 327–333. [[Medline](#)] [[CrossRef](#)]
- 8) Wong YS: Influence of the abductor hallucis muscle on the medial arch of the foot: a kinematic and anatomical cadaver study. *Foot Ankle Int*, 2007, 28: 617–620. [[Medline](#)] [[CrossRef](#)]
- 9) Goo YM, Heo HJ, An DH: EMG activity of the abductor hallucis muscle during foot arch exercises using different weight bearing postures. *J Phys Ther Sci*, 2014, 26: 1635–1636. [[Medline](#)] [[CrossRef](#)]
- 10) Sakamoto AC, Teixeira LF, Rodrigues F, et al.: Gluteus maximus and semitendinosus activation during active prone hip extension exercises. *Braz J Phys Ther*, 2009, 13: 335–342. [[CrossRef](#)]
- 11) Cote KP, Brunet ME, Gansneder BM, et al.: Effects of pronated and supinated foot postures on static and dynamic postural stability. *J Athl Train*, 2005, 40: 41–46. [[Medline](#)]
- 12) Vicenzino B, Franettovich M, McPoil T, et al.: Initial effects of anti-pronation tape on the medial longitudinal arch during walking and running. *Br J Sports Med*, 2005, 39: 939–943, discussion 943. [[Medline](#)] [[CrossRef](#)]

- 13) Mattila VM, Sillanpää PJ, Salo T, et al.: Can orthotic insoles prevent lower limb overuse injuries? A randomized-controlled trial of 228 subjects. *Scand J Med Sci Sports*, 2011, 21: 804–808. [[Medline](#)] [[CrossRef](#)]
- 14) O’Sullivan K, Kennedy N, O’Neill E, et al.: The effect of low-dye taping on rearfoot motion and plantar pressure during the stance phase of gait. *BMC Musculoskelet Disord*, 2008, 9: 111–120. [[Medline](#)] [[CrossRef](#)]
- 15) Franettovich M, Chapman A, Vicenzino B: Tape that increases medial longitudinal arch height also reduces leg muscle activity: a preliminary study. *Med Sci Sports Exerc*, 2008, 40: 593–600. [[Medline](#)] [[CrossRef](#)]
- 16) Lange B, Chipchase L, Evans A: The effect of low-Dye taping on plantar pressures, during gait, in subjects with navicular drop exceeding 10 mm. *J Orthop Sports Phys Ther*, 2004, 34: 201–209. [[Medline](#)] [[CrossRef](#)]